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Differences in explosive strength values for students of the faculty of physical education and sports (male) according to body mass index levels

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Abstract

Background and Study Aim Explosive strength/muscular strength is demanded at the level of different body segments and regions in most sports. The purpose of the research: is to identify the differences in the manifestation of explosive force between groups of underweight, normal weight and overweight university students; to determine the associations between the anthropometric parameters and the value of the results in the applied tests.

Material and Methods The investigated group consists of 147 students (men) of the Faculty of Physical Education and Sport, divided into 3 distinct groups for the analysis of the results: underweight (age=20.40±1.18, BMI=17.81±0.93), normal weight (age=20.504±1.671, BMI =22.24±1.67) and overweight (age=22.44±2.24, BMI=28.01±2.74). 7 tests were used to evaluate the explosive strength of the lower body (Vertical Jump Test, Standing Long Jump Test, 3-Hop Test, The multiple 5 bounds test, 30s Lateral double leg hop test, 30s Continuous vertical jumps, Speed Test 10m). A number of 6 tests were used to evaluate the explosive strength of the upper body (Overhand ball throw, Shot put, Overhead Medicine Ball Throw-forward, Overhead Medicine Ball Throw-backward, Medicine ball chest throw, 30s Plyometric Push-Ups).

Results Univariate test results indicate F values associated with significant thresholds at the lower body level ($P<0.05$) for tests based on horizontal jumps (Standing Long Jump, 3-Hop Test and The multiple 5 bounds test), where underweight and normal weight have the better average scores. At the level of the upper body, the situation is changed (for Shot put and medicine balls throws), where the overweight have the best average values, followed by the normal weight, and the worst results are found for the underweight group ($P<0.05$). Only for the Overhand ball throw and 30s Plyometric Push-Ups, the superiority of the overweight is not statistically confirmed ($P>0.05$). Correlation calculation (Pearson values) indicates positive associations between body height and vertical and horizontal jumps (except for those repeated for 30s), but negative associations of BMI and body mass with jump-based tests. However, BMI and body mass are moderately, positively and significantly correlated with throw-based tests ($P<0.05$).

Conclusions We can state that the classification of students in different BMI categories generates differences in explosive strength values between the 3 studied groups. The comparisons indicate the superiority of underweight and normal weights over overweight in all lower body explosive strength tests. The comparisons indicate also the significant superiority of overweight in the medicine ball and shot put tests over normal and underweight. The obtained results cannot be generalized, due to the small size of the underweight and overweight samples. Further investigations on larger groups of university students being necessary.

Keywords: muscle strength, university students, explosive efforts, BMI levels, differences, evaluation.

Introduction

In the system of motor skills, muscle strength and power play a major role in the manifestation and exploitation of motor potential in ontogeny [1]. The identification of talent characteristics for elite teenagers (according to the characteristics of 9 different sports) indicates the importance of the explosive strength of the lower limbs and overhead-throwing skills in volleyball and badminton, respectively agility and sprint/speed in soccer, volleyball, badminton and judo [2]. A longitudinal study of children and adolescents from several countries revealed an improvement in Standing long jump performance between 1960 and 1990, then a stagnation until the year 2000, followed by a decline in performance to the present, for most of the analyzed countries. However, no associations were noted between the decrease in functional explosive

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strength of the lower body and socio-economic or health indicators [3].

Physical activity, somatic type and body composition are factors that strongly influence the explosive strength of the lower body. Comparative studies between athletic vs. non-athletic university students (22.16 years old) showed higher VJT values for those who were physically active, with an increased percentage of skeletal muscle mass and belonging to the mesomorph/ectomorph types. Endomorphs, non-athletes and those with high body mass values perform poorly in vertical jump tests [4]. The presence of jumping asymmetries for young adolescent athletes (both genders) involved in team sports (basketball, handball and volleyball) is a factor associated with a reduction in short-distance sprint and jumping test performances [5]. Comparison of the motor performance of Hungarian athletic (basketball) and non-athletic university students shows only height variations in favor of basketball players, but they perform better in vertical jump and balance tests, and high BMI values are negatively correlated with physical performances [6]. Research on Nigerian university students, recreational basketball players (19.12 years) indicated strong correlations between the Vertical jump test (VJT) value and a series of anthropometric data (height, weight, BMI values, calf girth and foot length). However, no significant associations were reported between VJT with femoral length, thigh girth, tibial length [7]. Testing the fitness level of Brazilian adolescents identifies poorer performance of overweight and underweight, including SLJ explosive strength and medicine ball throw assessment [8]. Other research (on the level of university students majoring in medicine) reports negative associations of BMI with lower body explosive strength, but also positive associations between the amount of muscle tissue and vertical jump values [9]. A study of Brazilian junior soccer players revealed significant negative associations between VJT performance and agility tests with body fat percentage, so increased body fat percentage affects vertical jump values [10]. Muscle power performances for elite league Greek handball players vary by ranking position/rank. For the team in the first place, better results are obtained in the vertical jump test, compared to the team in the 8th place out of 11 clubs, the situation being similar in the Continuous vertical jumps 30s test. The results can also be explained by the higher average height as well as the greater amount of lean muscle mass of the champion team [11].

For Brazilian adolescent wrestlers, positive and strong associations between horizontal jumps and body height are highlighted, and for judo practitioners, significant associations are reported between body mass and body height with the medicine ball chest throw and VJT tests. Judoka has superior performances in 3 kg medicine ball chest throw, VJT, standing long jump test (SLJ) [12]. The quality of technical executions in different sports disciplines depends on the value/level of the athletes and the values of the explosive force at the level of the muscle chains involved in the effort, the aging of the body and the degeneration of the musculoskeletal system. Increased values of body fat percentage affect motor performance and sports results [13, 14, 15, 16]. At the level of young track and field (shot-put) practitioners, performances in this athletic test are correlated with several factors: the volume of the muscles of the upper and lower body, peak power output (PPO) of arms and legs. Other important factors are work of hand action force (WHAF) and release velocity parameter [17]. Parameters related to fitness level and motor skills are relevant for the selection of elite archers in a Malaysian youth group. The best was found to score higher in balance, strength and other skills, including muscle power, as assessed by the Vertical jump test and Standing long jump [18]. Other authors demonstrate the importance of the psychological factor in achieving performance in muscle strength tests. The use of external stimuli (performance feedback and verbal encouragement) has a beneficial effect on explosive strength test performance (Speed test 10 m and Vertical jump test) for physically active and inactive university students in Saudi Arabia [19].

Sports subjects (team sports games, combat sports, track and field) have higher explosive force values compared to physically active but non-sporting subjects, as a result of adaptive changes of the body [20]. A direct effect of physical effort and systematic training is the improvement of physical performance, as a result of morphological and functional adaptations to various demands [21, 22, 23]. However, the installation of muscle fatigue affects the performance related to the strength of the lower body, being found significantly lower values in the vertical and horizontal jumps after physical effort, compared to those before the effort. The studies were carried out on subjects involved in recreationally trained physical activities, but also on the level of adult groups, according to Cooper et al. and Leister et al. [24, 25]. Studies on athletes have shown that the onset of muscle fatigue generates a limitation of vertical jump height performance. Performing repeated vertical jumps for 30 s with a load of 30% of the body weight value generated a significant decrease in Vertical jump values after 3 minutes of rest. Retesting after 4 minutes and 5 minutes identified an increase in performance, as a result of the effect of PAP/ post activation potentiation that generates an acute production of muscle strength [26].

Regarding the training methodology aimed at increasing explosive strength for various sports and at the level of different muscle chains, specialized studies are numerous. The survey of strength and conditioning coaches (SCCs) from various countries and sports branches identifies that multiple hops/ lunges are most often programmed (84%) as variations of plyometric exercises. About 40% of coaches want to use as much technology as possible in the developed programs for training athletes and training aimed at optimizing muscle strength [27]. Using various medicine ball throws (medicine ball twist throw, medicine ball chest throw, medicine ball forward overhead throw) alleviates shoulder and arm strength deficit for Indonesian students [28]. Studies on Japanese university student athletes (20.2 years old) confirm the usefulness of using training programs that include push-ups (with similar load to 40% 1RM bench press) in terms of muscle hypertrophy and the increase in explosive strength in the medicine ball throw test [29].

Purpose of the Study. Our research aims to verify the following directions:

1. Determining possible differences in the lower and upper body explosive strength tests between the 3 BMI categories (underweight, normal weight and overweight) for (male) students of the Faculty of Physical Education and Sport in Galati
2. Identifying the value and significance of the associations between the somatic parameters and the results of the applied tests.

Materials and Methods

Participants

Our group consists of 147 university students (men) enrolled in undergraduate studies (years 1 and 2), within the Faculty of Physical Education and Sport in Galati - Lower Danube University in Galati. Of these, 99 are performance athletes, and 48 are non-athletes (but physically active in curricular and leisure activities), the division into groups for processing and analysis of the results being made according to BMI levels. These are: underweight (N=15, age= 20.40±1.18), normal weight (N=107, age=20.504±1.671) and overweight (N= 25, age=22.44±2.24). Additional data related to the group structure and anthropometric characteristics are presented in table 1, the numerical imbalance between the 3 formed groups being obvious.

Research Design

Our study is based on a cross-sectional investigation, planned in May 2019, within the Research Center for Human Performance of the Faculty of Physical Education and Sports in Galați (Romania). The participants will receive information related to the purpose of the research and the execution technique of the explosive force evaluation tests. All rules related to scientific research involving human subjects, according to the Helsinki Declaration, were followed [30, 31]. The students were instructed not to engage in demanding efforts before the tests, in order not to affect the obtained performances. The warm-up was based on aerobic demands at reduced intensities and dynamic stretching with the mobilization of the joints and muscle chains required for the tests. The evaluation was scheduled over 2 days, separately for the lower and upper body, due to the large number of samples. 7 lower body (A) explosive strength evaluation tests and 6 upper body explosive strength evaluation tests (B) were planned. Information related to the validity and description of the tests is provided by [32, 33, 34, 35, 36, 37, 38].

(A) 1. Vertical Jump Test/VJT (Sargent Jump test)/*cm*, 2.Standing Long Jump Test/SLJ (Standing Broad Jump)/*cm*, 3. 3-Hop Test (3 double leg jumps)/ *cm*, 4. The multiple 5 bounds test/MB5/(5 forward jumps with alternative left and right leg contacts)/ *cm*, 5. 30s lateral double leg hop test (30-Second Endurance Jump- jumping over an obstacle/rope or fence raised at the height of the knees)/*number of executions*, 6. 30s Continuous vertical jumps / Modified Bosco Repeat Vertical Jump Test 30 s by touching a sign or object raised to 2/3 of the personal best jump/ maximum jump height/ *number of executions*, 7. Speed Test 10m (Sprint test 10m)/*s*.

(B) 1. Overhand ball throw (140 grams and 8cm diameter) *(m),* 2. Shot put-track and field - 4kg women and 7.260kg men/*cm*, 3. Standing Overhead Medicine Ball Throw-forward (3 kg)/*cm,* 4. Standing Overhead Medicine Ball Throw-backward (3kg)/*cm* 5. Standing medicine ball chest throw (3kg)/*cm,* 6. 30s Plyometric Push-Ups/clap push-ups/ *number of executions*.

Statistical Analysis

The data obtained from the tests were statistically processed with SPSS Software (Statistical Package

Table 1. Distribution of students into groups and analyzed anthropometric characteristics (average and standard deviation)

Indicator	Subjects	Athletes	Non-athletes	Height	Weight	BMI
Underweight	15(10.22%)	8(5.44%)	7(4.78%)	180.333±8.861	58.3000±7.936	17.816±0.935
Normal weight	107(72.78%)	75(51.02%)	32(21.76%)	178.602±6.328	71.102±7.8751	22.249±1.670
Overweigh	25(17.00%)	16(10.88%)	9(6.12%)	178.460±6.597	89.040±6.3507	28.016±2.741

for the Social Sciences/IBM Vers.24 Chicago, IL, USA). ANOVA parametric techniques were used (multivariate and univariate test, highlighting the values of F, significance thresholds and size effect/ Partial eta squared /η^2_p , Levene's Test of Equality of Error Variances. Were calculated data related to the averages of the 3 BMI groups in the tests, the differences between them and their significance with the application of Bonferroni Post Hoc Tests. The Pearson parametric correlations (r) were calculated between the anthropometric indicators and the value of the performances in the muscle strength tests. The confidence interval was set at 95% ($p < 0.05$) [39, 40, 41, 42, 43].

Results

Table 2 summarizes the information resulting from the multivariate test, tables 3 and 4 the univariate test results for the lower and upper body. Tables 5 and 6 identify the significance of the differences between the averages of the resulting pairs (by BMI levels), and tables 7 and 8 summarize the value of the correlation coefficients between the anthropometric indicators and the set of applied tests.

The global effect of the independent variable BMI levels on the performances in the strength tests for the tested students (Multivariate Tests) is presented in table 2. The value F is associated with a statistically significant threshold ($p < 0.05$), an aspect also reinforced by the η^2_p value (expression of size effect), which indicates that 20.4% of the variance in the applied tests is generated/explained by the variable BMI levels.

The influence of the independent variable on the explosive force evaluation tests in the lower limbs is summarized in table 3. It is observed that significant thresholds of F ($P<0.05$) are obtained only in tests based on horizontal jumps (Standing Long Jump, 3-Hop Test and The multiple 5 bounds test). However, ^2_p values indicate that an average effect size for The multiple 5 bounds test (where 8.4% of the performance variance is explained by the BMI levels variable), in the other two cases low and medium effect size values were obtained. For vertical jumps, repeated jumps and the 10m sprint, all thresholds obtained are insignificant ($P>0.05$), and the η^2_p values indicate weak and null effect sizes, so in these tests no significant influence of BMI levels on muscle strength is found of the lower body.

The results of the analysis of variance for upper body explosive strength are summarized in Table 4. Significant thresholds for F values ($P<0.05$) are identified for all tests involving throwing heavy objects (the 3 variants of throwing the medicine ball and Shot put – track and field). In these cases, strong and medium η^2_p values are also obtained (for example, for Shot put 14.2% of the variance of the results is determined by the influence of BMI

Table 2. The results of the Multivariate Tests (MANOVA[a])

Gender	Effect	λ	F	Hypothesis df	Error df	Sig.	η^2_p	Observed Power
Male	BMI levels	0.634	2.595[b]	26.000	264.000	0.000	0.204	1.000

a. Design: BMI levels; b. Exact statistic;

λ-Wilk's lambda; F-Fisher test; df-degrees of freedom; Sig.-level of probability; η^2_p-partial eta squared

Table 3. Univariate test results (ANOVA) – The effect of variable BMI levels on the performances in lower body strength tests

Dependent Variable	Sum of Squares	Mean Square	F (2, 144)	Sig.	Partial Eta Squared	Observed Power
Vertical Jump Test/VJT	37.703	18.851	0.496	0.610	0.007	0.130
Standing Long Jump Test/SLJ	2442.195	1221.097	3.914	0.022	0.052	0.698
3-Hop Test	23044.884	11522.442	3.245	0.042	0.043	0.610
The multiple 5 bounds test/MB5	124330.803	62165.402	6.609	0.002	0.084	0.907
30s lateral double leg hop test	257.277	128.638	2.247	0.109	0.030	0.452
Speed Test 10m	0.053	0.026	2.488	0.087	0.033	0.493
30s Continuous vertical jumps	21.623	10.811	0.935	0.395	0.013	0.210

Table 4. Univariate test results (ANOVA) – The effect of variable BMI levels on the performances in upper body strength tests

Dependent Variable	Sum of Squares	Mean Square	F (2, 144)	Sig.	Partial Eta Squared	Observed Power
Overhand ball throw (OBT)	69.922	34.961	0.686	0.505	0.009	0.164
Shot put -track and field	243239.472	121619.736	11.873	0.000	0.142	0.994
Overhead Medicine Ball Throw-forward 3kg	396630.905	198315.452	7.541	0.001	0.095	0.941
Overhead Medicine Ball Throw-backward 3kg	443911.827	221955.913	6.970	0.001	0.088	0.922
Medicine ball chest throw 3kg	140055.364	70027.682	6.132	0.003	0.078	0.883
30s Plyometric Push-Ups/clap push ups	113.179	56.590	1.122	0.329	0.015	0.244

levels). Non-significant thresholds of F (P>0.05) are registered only for Overhand Ball Throw and 30s Plyometric Push-Ups, where the size effect values are also weak or null, so in these cases performances are not decisively influenced by BMI levels.

The differences between the average scores at the level of the BMI pairs, for the explosive force of the lower body, are shown in table 5. They capture the superior scores of the underweights in almost all tests (except for 30s Continuous vertical jumps, where the normal-weights have the best average), and the overweight group has the worst results in all tests, among all tested groups. However, few significant differences (P<0.05) are reported and these are between the underweight and overweight groups for the 3 horizontal jump tests. Even if the normal weight group has higher values than the overweight group in all tests, we identified only one significant difference between these 2 groups (for The multiple 5 bounds test). The average values of the normal weight group are close to those of the underweight group, with only insignificant differences being reported (P>0.05). We found that regular physical activity reduces the gaps and mitigates the variations in explosive strength performances between the compared groups, in 4 of the 7 tests evaluated.

The average values and the differences between them at the level of the 3 pairs for the explosive strength of the upper body are shown in table 6. We find a major change, in the sense that the overweight group has the superiority in these tests, followed by that of the normal weight group, and the worst results belong to those in the underweight group. The differences are statistically significant (P<0.05) for the Shot put test and the medicine ball throwing variants, both between the overweight and underweight groups, and between the overweight and normal weight groups. This situation can be explained by the composition of the group of overweight athletes, involved in rugby, handball, fitness/bodybuilding and combat sports, where the level of muscle mass development and the demands of the upper body are obvious. Only insignificant differences (P>0.05) are reported between the underweight and normal weight groups, even though normal weight has better average scores in all tests. No significant differences were recorded between the groups for the overhand ball throw and 30s Plyometric Push-Ups, so the superiority of the average performances for normal weight and overweight is not statistically confirmed.

Associations between anthropometric indicators and lower body explosive strength values are shown in Table 7. Body mass and BMI levels are negatively associated with most leg strength test performances, except Speed test 10m. Height shows weak and significant positive associations (P<0.05) with vertical and horizontal jumps, but also negative associations with repeated jumps and Speed test 10m. Most of the weak but significant (P<0.05) negative associations with the tests are observed at the BMI level, so increasing BMI and body mass indices are correlated with decreased muscle power in all jumps, but weakly, positively and significantly correlated with short distance sprint. This aspect that must take into account the fact that, in the sprint, the increase in the result actually highlights a weaker performance, so a negative influence of BMI and body mass can also be discussed.

The associations between the anthropometric indicators and the explosive strength tests of the upper body (Table 8) are materialized in weak and medium correlation coefficients, but statistically significant (P<0.05) at the Shot put level and the 3 medicine ball throwing tests. We can state that the tall students and with increased values of muscle mass and BMI index have better values in tests of throwing heavy objects. The aspect is not confirmed for throws with light objects and for plyometric push-ups, where all correlation coefficients obtained are statistically insignificant (P>0.05).

Discussion

Other similar research also identifies differences between lower and upper body explosive strength

Table 5. Synthesis of average values and differences obtained between the 3 BMI categories for lower body explosive strength (underweight=15, normal weight=107, overweight=25)

Test	Group	Mean	Std. deviation	Std. error	a-b	Sig.[b]	a-c	Sig.[b]	b-c	Sig.[b]
Vertical Jump Test/ VJT	a. underweight	44.066	6.250	1.592	0.751	1.000	1.867	1.000	1.116	1.000
	b. normal weight	43.315	6.154	0.596						
	c. overweight	42.200	6.159	1.233						
Standing Long Jump Test/SLJ	a. underweight	234.667	13.854	4.561	8.732	0.225	15.987*	0.019	7.255	0.200
	b. normal weight	225.934	18.231	1.708						
	c. overweight	218.680	17.087	3.533						
3-Hop Test	a. underweight	720.533	47.112	15.387	26.571	0.324	49.053*	0.038	22.483	0.275
	b. normal weight	693.962	60.608	5.761						
	c. overweight	671.480	61.550	11.918						
The multiple 5 bounds test/ MB5	a. underweight	1176.400	110.702	25.042	45.690	0.269	108.400*	0.002	62.710*	0.013
	b. normal weight	1130.710	98.208	9.376						
	c. overweight	1068.000	81.798	19.397						
30s lateral double leg hop test	a. underweight	32.800	5.857	1.954	0.529	1.000	3.960	0.334	3.431	0.129
	b. normal weight	32.271	7.587	0.732						
	c. overweight	28.840	8.320	1.513						
Speed Test 10m	a. underweight	1.874	0.099	0.027	-0.011	1.000	-0.059	0.244	-0.048	0.108
	b. normal weight	1.885	0.099	0.010						
	c. overweight	1.933	0.119	0.021						
30s Continuous vertical jumps	a. underweight	20.866	3.758	0.878	-0.358	1.000	0.667	1.000	1.024	0.531
	b. normal weight	21.224	3.320	0.329						
	c. overweight	20.200	3.523	0.680						

*The mean difference is significant at the .05 level. [b]Adjustment for multiple comparisons: Bonferroni.

values, most of which are in agreement with the results obtained in our study.

Excess body mass induces negative effects on lower body muscle strength tests, an aspect signalled by the analysis of young Greek basketball players. In the U18 group, average countermovement/CMJ performances of 40 cm for those of normal weight and 37.3 cm for overweight ones are obtained. For the SLJ test a performance of 248 cm for those of normal weight and 229 cm for overweight ones is reported. Even though in the Speed Test 10m both groups have equal values (1.91s), for the U15 and U12 groups, weaker results are obtained for the overweight [44]. Other research reports a decline in fitness levels for university students [4, 6, 18, 45]. The results are in accordance with those obtained by us, where the underweight and normal-weight have superior values compared to the overweight in horizontal jumps.

Jump values are higher for athletic Indian university students (23.86 years) compared to those not engaged in regular physical activity (22.16 years). At VJT, athletes get 49.13cm, compared to 42.41cm for non-athletes. The values of the explosive force of the lower limbs are positively correlated with the ectomorph and mesomorph constitutional types, low body mass and the percentage of muscle tissue, respectively negatively correlated with the endomorph type, weight and body fat percentage [46]. A longitudinal study of university students in Taiwan (20–24 years) identified stronger negative associations between BMI and standing long jump (SLJ) strength for men compared to women. Average values of 201.87 cm for men and 149.66 cm for women are obtained for the participants [47]. Significant differences between Indian male university student athletes and non-athletes are highlighted for VJT (49.13cm vs 42.41cm). Performances for explosive leg strength are positively associated with mesomorph and ectomorph somatic type, lean body

Table 6. Synthesis of average values and differences obtained between the 3 BMI categories for upper body explosive strength (underweight=15, normal weight=107, overweight=25)

Test	Group	Mean	Std. deviation	Std. error	a-b	Sig.b	a-c	Sig.b	b-c	Sig.b
Overhand ball throw	a. underweight	39.226	7.437	1.844	-2.076	0.881	-2.619	0.790	-0.544	1.000
	b. normal weight	41.302	6.481	0.690						
	c. overweight	41.846	9.389	1.428						
Shot put -track and field	a. underweight	581.733	81.223	26.132	-64.454	0.067	-151.867*	0.000	-87.413*	0.000
	b. normal weight	646.186	93.152	9.784						
	c. overweight	733.600	138.871	20.242						
Overhead Medicine Ball Throw-forward	a. underweight	822.667	196.292	41.871	-56.903	0.615	-180.533*	0.003	-123.630*	0.002
	b. normal weight	879.570	147.866	15.677						
	c. overweight	1003.200	196.822	32.433						
Overhead Medicine Ball Throw-backward	a. underweight	1090.933	189.227	46.075	-73.637	0.410	-198.587*	0.003	-124.950*	0.006
	b. normal weight	1164.570	169.714	17.251						
	c. overweight	1289.520	207.270	35.690						
Medicine ball chest throw	a. underweight	764.533	114.092	27.592	-55.962	0.179	-118.107*	0.003	-62.145*	0.029
	b. normal weight	820.495	106.723	10.331						
	c. overweight	882.640	103.058	21.373						
30s Plyometric Push-Ups/ clap push ups	a. underweight	13.733	5.509	1.834	-2.874	0.433	-2.987	0.600	-0.113	1.000
	b. normal weight	16.607	7.086	0.687						
	c. overweight	16.720	7.950	1.421						

*The mean difference is significant at the .05 level. bAdjustment for multiple comparisons: Bonferroni.

Table 7. The value of the Pearson correlation coefficients between anthropometric indicators and lower body explosive strength tests

Variable		Vertical Jump Test	Standing Long Jump	3-Hop Test	The multiple 5 bounds test	30s lateral double leg hop test	30s Continuous vertical jumps	Speed Test 10m
Weight	r (value)	-0.004	-0.141	-0.123	-0.138	-0.306**	-0.173*	0.181*
	Sig.	0.959	0.089	0.137	0.095	0.000	0.036	0.028
Height	r (value)	0.212*	0.156	0.199*	0.354**	-0.196*	-0.084	0.136
	Sig.	0.010	0.058	0.015	0.000	0.017	0.312	0.101
BMI	r (value)	-0.118	-0.250**	-0.253**	-0.333**	-0.247**	-0.146	0.269**
	Sig.	0.154	0.002	0.002	0.000	0.003	0.078	0.001

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

mass and % skeletal muscle mass, and negative associations are reported with endomorph somatic type, % body fat, weight and body surface area [46]. Our research supports these findings, identifying negative associations between BMI values and all types of jumping tests.

For the sedentary Indian university students in Calcutta (21-25 years old), average vertical jump test/CMJ values of 47 cm for men and very poor values of 22.05 cm for women are obtained. The high percentage of adipose tissue is a factor that limits the value of performances in this test [48]. We have identified a statistically significant superiority of the underweights over the overweight ones, for all variants of horizontal jumps. Weight loss (by ketogenic diet) for Korean Taekwondo practitioners

Table 8. The value of Pearson correlation coefficients between anthropometric indicators and upper body explosive strength tests

Variable		Overhead ball throw	Shot put	Overhead Medicine Ball Throw-forward	Overhead Medicine Ball Throw-backward	Medicine ball chest throw	30s Plyometric Push-Ups
Weight	r (value)	0.101	0.508**	0.483**	0.450**	0.459**	0.067
	Sig.	0.226	0.000	0.000	0.000	0.000	0.423
Height	r (value)	0.141	0.330**	0.381**	0.311**	0.380**	-0.024
	Sig.	0.088	0.000	0.000	0.000	0.000	0.773
BMI	r (value)	0.035	0.401**	0.355**	0.342**	0.322**	0.082
	Sig.	0.670	0.000	0.000	0.000	0.000	0.326

** Correlation is significant at the 0.01 level (2-tailed)

shows beneficial effects related to increased aerobic capacity and fatigue resistance. For the SLJ/ Standing broad jump, however, a slight decrease in performance is noted, from 229.6cm to 227.55cm, a similar situation being also reported for the sprint test [49]. These results are above the average values obtained by our normal weight and overweight groups, but our underweight group achieves a higher average value (234.667cm).

Elevated body fat values negatively influence performance in all short-distance sprint and explosive strength tests for young Qatari handball players (16.55 years) selected from all playing positions. At the CMJ, the normal-weight achieve 32.61cm and the obese 31.15cm, and at the 3 kg medicine ball chest throw/MBCT the normal-weight have a result of 840cm vs 769cm for the obese [50]. The results of our overweight group do not confirm these findings for the medicine ball throws (where they perform better) and they do confirm for the vertical jump (where the average values are poorer). Values in explosive strength and agility tests (T-test, 10m sprint, VJT) for Qatari handball players are much better for those with a low percentage of adipose tissue. However, the medicine ball overhead throw-forwards test is the only one in which the average value of the overweight is higher than that of the normal weight [51]. For Polish university students (20 years old), negative associations are reported between BMI values and increased body mass with almost all muscle strength tests. However, positive correlations are identified for medicine ball throw variants, men achieve a maximum score of 1283cm for Medicine ball forward throw, 1745cm for Medicine ball backward throw and 278cm for SLJ [52]. The higher values of the overweight for the medicine ball throwing tests are also confirmed by our study, with significant differences compared to the normal and underweight students.

Studies on young football/soccer players (U16, U17 and U-19) highlight the superiority of those who play more minutes in matches, compared to those with fewer playing minutes, in terms of aerobic fitness. However, no significant differences and correlations are reported at the level of anaerobic power (vertical and horizontal jumps) or for Body fat between the two studied categories. For the U19 group, 740cm are obtained in the triple hop test and 40cm in the CMJ, the fitness level being better with advancing age [53]. The triple hop test performance is superior to all the average values obtained by our groups, a possible explanation being the exclusive presence of performance athletes, within our subgroups there are also students who are not constantly involved in performance sports. Body height and vertical jumps are important aspects for the performance of volleyball players (elite level) whose lower body explosive strength test values differ according to the position on the court. The top results for CMJ are obtained by opposite hitters and outside hitters/receivers (57.4 cm), and the best CMJ (with arm swing) values are also reported for the same positions (70.67 cm), according to [54]. Our study identifies positive associations between body height and vertical jump performance, except for 30-second repeated jumps (vertical and horizontal), where the associations are negative.

The comparison of CMJ test values between Brazilian judoka athletes (20.5 years) and Brazilian jiu-jitsu (BJJ) athletes, identifies higher but statistically insignificant scores for judoka (46.56 cm vs. 45.33 cm). For the advanced level groups, the performances are higher and relatively balanced (48.44 cm vs. 48.41 cm). For both disciplines, higher values of experienced athletes are found, compared to beginners/novices, so experience and physical accumulations have a role in the manifestation of explosive strength [55]. Investigation of young track and field sprinters (18 years) indicated strong associations between short-distance sprint/ acceleration test performance with vertical jump explosive strength and body height [56].

The use of Trampoline Exercise (20 weeks x 4 sessions per week) for Iranian adolescents has effects on increasing calf girth, but also on optimizing the anaerobic power of the lower limbs, with very good values for VJT (71cm) and SLJ (218cm), according to [57]. Our values for VJT are weaker, but at the SLJ level only the overweight group has a similar performance, and the underweight and normal weight groups have higher average scores. The efficiency of plyometrics in optimizing the explosive strength of the lower limbs is demonstrated on Algerian university students, majoring in Physical Education and Sports (19 years old). They obtain SLJ values of 241cm, compared to 228cm for those who followed a traditional strength development program, the performances being optimized in the triple jump/athletic test and in the short-distance sprint [58]. In this case we note that all 3 of our groups have lower values at SLJ, compared to the value of those who exclusively used plyometrics in training.

Arm muscles are important in serving in tennis, and using push up variations generates increases in muscle strength for Indonesian university student athletes, with final values of 16.38 push-ups [59]. Our overweight and normal weight groups have similar average results, and the underweight group has a poorer score of just 13,733 push-ups.

For male recreational athletes (22.6 years old) involved in team sport games (soccer, basketball, rugby, baseball) values of 1.76s are obtained in the 10m acceleration test. Short-distance sprint values are significantly correlated with unilateral vertical and horizontal jump performance [60]. For US male collegiate student athletes (21.1 years), the following leg muscle strength values are obtained: VJT (51.72cm), SLJ (240.44cm), 10 Yard Sprint (1.72s). Negative associations are identified between SLJ performance and short distance sprint times [61]. All of these studies show leg muscle strength values superior to our students. A comparative analysis of the effectiveness of plyometrics vs electrostimulation for predominantly male Indian badminton players (where agility and vertical jumps are specific demands) identifies better short-distance sprint progress with the plyometric variant. For lower limb explosive strength both methods are efficient, but electrostimulation generated better average results than plyometrics at VJT (55.93cm vs 48.26cm) and at SLJ (237.53cm vs 226.46cm) [62]. In this case also, our groups obtained poorer results than those previously presented. Various sports (soccer and judo) require skills related to strength, speed and motor coordination, with an effect on competition performance. The use of speed-jumping training (various horizontal and vertical jumps) for these sports (Polish teenagers) leads to increases in explosive strength at the level of the legs. The results are better for soccer players: in SLJ 227.2cm vs 225.4cm, and at 3-Hop Test 700.8cm vs 680.4cm [63]. In this case, our underweight group has better average scores on both tests, the normal weight group has similar values, and the overweight group has lower average values.

Conclusions

Univariate tests results indicate F values associated with significant thresholds at the level of the lower body ($P<0.05$) for tests based on horizontal jumps (Standing Long Jump, 3-Hop Test and The multiple 5 bounds test). Similar significant values are obtained at the upper body level for Shot put and medicine ball throws (Overhead Medicine Ball Throw-forward, Overhead Medicine Ball Throw-backward and Medicine ball chest throw). Group comparison according to BMI levels indicates the superiority of underweight and normal weight over overweight in all tests of lower body explosive strength. The situation is reversed for the upper body explosive strength tests, where the overweight has the best average values, followed by the normal weight, and the worst results are found for the underweight group. The only tests at the level of the upper body where the differences between the groups are statistically insignificant ($P>0.05$) are the Overhand ball throw and 30s Plyometric Push-Ups.

The correlations (r / Pearson values) between the anthropometric indicators and the results of the applied set of tests indicate positive associations between body height and vertical and horizontal jumps, except for repeated ones (lateral and vertical 30s). With the exception of the 10m speed test, body mass and BMI only show negative associations with jump-based tests, so increases in these indicators negatively influence performance in all types of jumps. The correlations recorded at the level of the upper body show average positive and, in most cases, significant values ($P<0.05$) of r for most tests, so increases in body mass, BMI and body height are associated with an improvement in results in all throwing tests.

The results of our study must be viewed with caution, the main limitation of the research being the numerical imbalance between the groups, with a low percentage representation of the underweight and overweight groups. Studies on larger and balanced samples are needed from this point of view. We believe that investigations based on the analysis of body composition would bring additional information related to the amount of active muscle mass, especially for the overweight group, and would provide scientific arguments related to their superiority in tests of explosive strength based on throws.

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Conflict of interest

No potential conflict of interest that is of any relevance to this study was reported by the authors.

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